EFFECT OF ENERGY CROP FINENESS ON FORCE OF EXTERNAL FRICTION

Boguslawa Lapczynska, Jaroslaw Fraczek, Zbigniew Slipek
University of Agriculture in Krakow, Poland
kordon@ar.krakow.pl

Abstract. The relationships between the fineness of the selected energy crops and the force of external friction have been determined. The effects of the tests indicate a statistically significant effect of the shape aspect of shredded giant miscanthus and willow on the value of static and kinetic friction. The non-linear models proposed, which describe the variations of the friction coefficient versus the shape factor of the studied material particles, are characterised by a high fidelity of matching and can be applied for forecasting the values of external friction of shredded plant material.

Keywords: external friction, plant material, energy crops.

Introduction

In classical tribology, external friction is defined as a set of phenomena occurring in the upper layers of solids moving relative to each other. In case of grainy centres of plant origin, they are ascribed the features of continuous centres, and the friction occurring between that material and the structural material is considered as the external friction.

Friction occurs in almost all processes of agricultural production and food processing industries. In case of plant materials, it is relatively little known. One of the main reasons for that is a large variety of such materials, their various physical state and complex anatomic and morphologic structure [3]. Another complication is that many properties determining the friction change in time, among others due to the internal physiological processes occurring in the plant material. This frequently results in a large scattering of measurement results [5]. In spite of that, learning the resistance involved in the movement and storage of scattered biological matter is vitally important from the perspective of designing and proper operation of process lines and planning the energy consumption [5]. Therefore, friction coefficient values have to be determined to describe the machine-plant relationship.

The EU preferences on the use of the so called renewable sources of energy have lead to an increased interest in the production of biomass derived from highly efficient energy crops [6]. Such crops included giant miscanthus – *Miscanthus giganteus* L. (characterised in C type photosynthesis, which predisposes it to use large amount of biomass and effective use of water [4]) and willow *Salix vinimalis* L. The structural and mechanical properties of those plants, particularly in the fragmented state, have not been studied well. This applies also to the external friction coefficient.

Among the factors determining the friction process, the most significant are considered the properties of materials forming the friction pair, including the water content in the plant material and geometrical features of individual particles [1, 2, 8, 9, 10].

Therefore, the objective of this paper has been to determine the relationship between the fineness of the material (determined by the size and shape of particles) of the selected energy crops and the force of external friction.

Materials and methods

The measurements were carried out on ground samples of M*iscanthus giganteus* L. and S*alix vinimalis* L., with the water content 0.09 $kg \cdot kg^{-1}$ dry mass. Variability of the static and kinetic (sliding) friction forces was analysed.

The plant material was shredded with a shredding machine and then with the KING type beater wheel mill. The resulting material was sieved through the LpzE-4e laboratory screen which allowed determination of the grain size composition. The equivalent diameter and shape factor of individual samples were also determined.

The friction force measurements were carried out with a MTS Insight strength testing machine with a special adapter (Fig. 1). Variable pressure force was taken into consideration (3, 13, 23, 33 and 43 N). A galvanised steel plate was used as the base. The sliding velocity was 0.03 $m \cdot s^{-1}$, and the measuring distance was 100 mm.

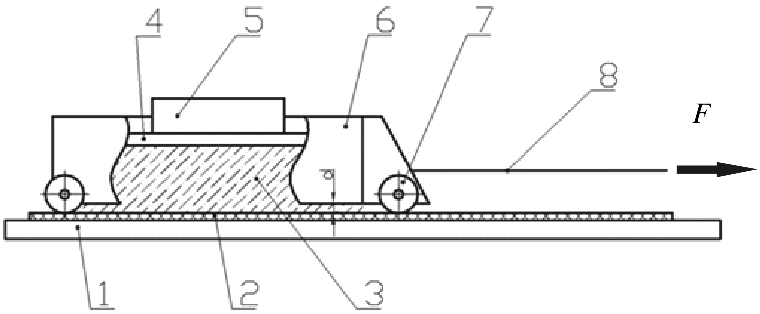

Fig. 1. **Diagram of the adapter for measuring the external friction force *F*:**
1 – base; 2 – structural material plate; 3 – tested material; 4 – cover; 5 – weight;
6 – casing; 7 – anti-friction bearing; 8 – linkage

The change of the friction force values was recorded at the frequency of 100 Hz, and the TestWork 4 software, operating with the strength testing machine created the force vs. displacement plot. A sample is shown in Fig. 2. The maximum force (F_1) recorded during the test is the static friction force, and the average force ($F_{śr}$) at the measuring distance L_p is the kinetic friction force.

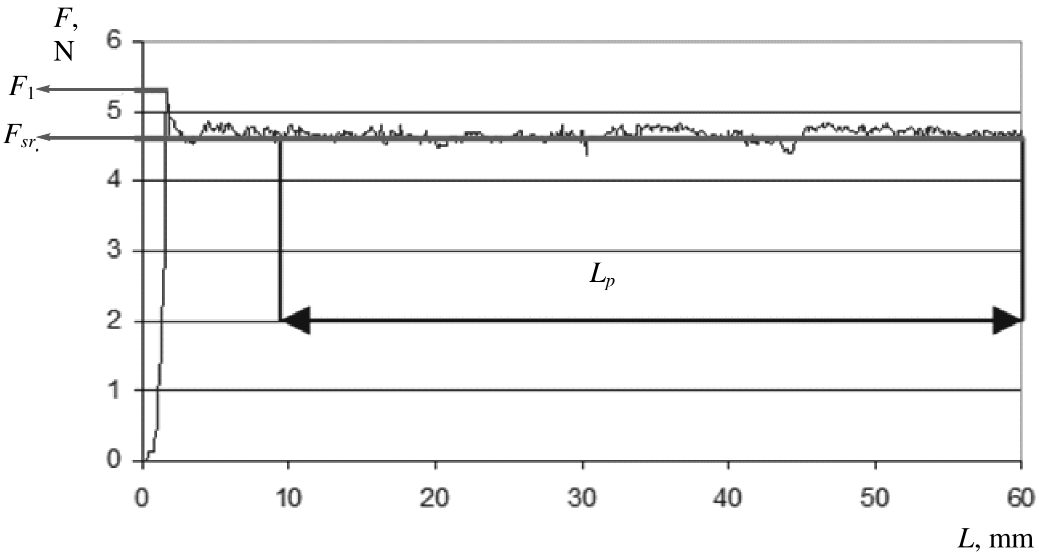

Fig. 2. **Relationship between the external friction and displacement:** F_1 – static friction force;
F_{sr} – kinetic friction force; L_p – measuring distance of the kinetic friction force

Individual material particles, as a rule, are of irregular shape, thus their linear dimension varies in different directions. Therefore, the specific linear dimension of such a particle can be its equivalent diameter d_z.

In the tests presented, as a result of a screen analysis of the grain material, a series of fractions with average diameters d_{z1}, d_{z2},..., d_{zi} were obtained, and the weight shares of an individual fraction were x_1, x_2,..., x_i respectively. An average equivalent diameter of the particles in the entire mixture was therefore calculated additively from the equation:

$$d_z = \sum_{n=1}^{N} x_i \cdot d_{zi} \tag{1}$$

where N – number of fractions.

The shape of the particles was determined based on the Curry's shape factor (sphericity):

$$S_n = \frac{D_i}{D_c} \tag{2}$$

where D_i – diameter of the largest circle inscribed in the particle body;
D_c – diameter of the smallest circle circumscribed on the particle body.

The Coulomb model was used to determine the friction force:

$$T = \mu N + C \tag{3}$$

where T – friction force, N;
μ – friction coefficient;
N – pressure, N;
C – cohesion force, N.

Results and discussion

The grain size analysis with a set of screens with the mesh sizes 16; 8; 3.2; 2.8; 2; 1.4; 1; 0.5; 0.25 and below 0.25 mm enabled the determination of the equivalent diameter and shape factor of the material tested.

The values of the static and kinetic friction coefficients, determined applying the Coulomb model, are shown in Table 1 and 2.

Table 1

Static friction coefficient and cohesion force of the material tested

Material	Properties of material		Static friction coefficient μ, -	Cohesion force C, N	Determination coefficient R^2
	Equivalent diameter	Shape factor			
Miscanthus giganteus L.	0.96	0.486	0.132	0.85	0.994
	1.26	0.531	0.174	0.99	0.992
	2.09	0.535	0.167	1.03	0.997
	5.54	0.458	0.153	0.81	0.990
	5.85	0.463	0.145	0.78	0.994
Salix vinimalis L.	2.18	0.579	0.177	0.88	0.998
	3.67	0.543	0.143	0.85	0.981
	4.57	0.495	0.229	1.08	0.998
	11.72	0.603	0.185	1.04	0.990
	13.49	0.501	0.156	0.79	0.970

A non-linear estimation was also performed which allowed determining the relationships between the sliding friction coefficient, the size of the material particles (d_z) and their shape (S_n):

$$\mu = ax^3 + ax^2 + cx + d \tag{4}$$

where μ – static friction coefficient;
x – shape factor S_n or equivalent diameter d_z;
a, b, c, d – constants.

The values of the model constants are shown in Table 3 and 4.

It was found that, in the entire measuring range, the values of the static and kinetic friction coefficients for the willow are much higher than those for the giant miscanthus. An attempt to describe the friction force with linear models proved that in case of both, the static and kinetic friction, the best match of the measurement results can be achieved with the Coulomb model.

The non-linear models proposed, describing the relationship between the friction coefficient and shape factor are characterised by high fidelity of matching, thus they can be applied for forecasting the changes of the friction force values. In case of the equivalent diameter, considerably lower determination coefficient was achieved.

Table 2

Kinetic friction coefficient and cohesion force of the material tested

Material	Properties of material		Kinetic friction coefficient μ, -	Cohesion force C, N	Determination coefficient R^2
	Equivalent diameter	Shape factor			
*Miscanthus giganteus*L.	0.96	0.486	0.122	0.37	0.994
	1.26	0.531	0.156	0.55	0.991
	2.09	0.535	0.147	0.26	0.994
	5.54	0.458	0.144	0.22	0.990
	5.85	0.463	0.133	0.12	0.991
Salix vinimalis L.	2.18	0.579	0.162	0.71	0.998
	3.67	0.543	0.137	0.47	0.993
	4.57	0.495	0.206	1.03	0.994
	11.72	0.603	0.173	0.91	0.991
	13.49	0.501	0.139	0.58	0.980

Table 3

Model constants for the static friction coefficient

Material	Property	*a*	*b*	*c*	*d*	R^2
*Miscanthus giganteus*L.	Equivalent diameter	0.0018	-0.0233	0.0845	0.0826	0.505
	Shape factor	-751.35	1130.5	-565.58	94.243	0.985
Salix vinimalis L.	Equivalent diameter	-0.00007	-0.0002	0.0167	0.1305	0.295
	Shape factor	-2092.1	3416.5	-1856.4	335.76	0.960

Table 4

Model constants for the kinetic friction coefficient

Material	Property	*a*	*b*	*c*	*d*	R^2
*Miscanthus giganteus*L.	Equivalent diameter	0.0005	-0.0088	0.0419	0.1	0.363
	Shape factor	-889.56	1332.6	-663.89	110.19	0.991
Salix vinimalis L.	Equivalent diameter	-0.0001	0.0007	0.0105	0.1277	0.411
	Shape factor	-472.73	794.56	-443.77	82.502	0.65

Conclusions

1. In the entire measuring range, the values of the static and kinetic friction coefficients for the willow are much higher than those for the giant miscanthus.
2. An attempt to describe the friction force with linear models proved that in case of both, the static and kinetic friction, the best match of the measurement results can be achieved with the Coulomb model.
3. Statistically significant effects of the shape factor on the static and kinetic friction coefficient were noted.
4. The non-linear models proposed, describing the changes of the static and kinetic friction coefficients, are characterised by high fidelity of matching, thus they can be applied for modelling the phenomena of external friction in shredded plant material. However, a lower determination coefficient was obtained for the equivalent diameter.

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